JC14 Rec'd PCT/PTO 17 JAN 2002

FORM PTO-1390 (REV 11-2000)	U.S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER **36-1535**
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S APPLICATION NO (If known, see 37 C.F.R 1 5) 10/031231 **Unknown**
INTERNATIONAL APPLICATION NO. **PCT/GB00/02997**	INTERNATIONAL FILING DATE **3 August 2000**	PRIORITY DATE CLAIMED **17 August 1999**

TITLE OF INVENTION

SIGNAL GENERATOR AND DECODER

APPLICANT(S) FOR DO/EO/US

WIDDOWSON et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☒ The U.S. has been elected by the expiration of 19 months from the priority date (Article 31).
5. A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has **NOT** expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 To 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information. Amended Sheets -- pages 3, 4, 4a and 12 and 13 (including claims 1-10 and 11 in part)

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U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.5) 10/031231	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
Unknown	PCT/GB00/02997	36-1535

21. ☒ The following fees are submitted:

BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):

-- Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00

-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $890.00

-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO $740.00

-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) $710.00

-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00

					CALCULATIONS		PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =					$	890.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).					$	0.00	
CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE			
Total Claims	13	-20 =	0	X $18.00	$	0.00	
Independent Claims	4	-3 =	1	X $84.00		84.00	
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)				$280.00	$	0.00	
TOTAL OF ABOVE CALCULATIONS =					$	**974.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.						0.00	
SUBTOTAL =					$	**974.00**	
Processing fee of $130.00, for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(f)). +						0.00	
TOTAL NATIONAL FEE =					$	**974.00**	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). **$40.00** per property +					$	40.00	
Fee for Petition to Revive Unintentionally Abandoned Application ($1280.00 – Small Entity = $640.00)					$	0.00	
TOTAL FEES ENCLOSED =					$	**1014.00**	
					Amount to be: refunded	$	
					Charged	$	

a. ☒ A check in the amount of $1014.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. 14-1140 in the amount of $_____ to cover the above fees. A duplicate copy of this form is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1140. A duplicate copy of this form is enclosed.

d. ☒ The entire content of the foreign application(s), referred to in this application is/are hereby incorporated by reference in this application.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

Larry S. Nixon
SIGNATURE

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25,640 — **January 17, 2002**
REGISTRATION NUMBER — Date

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

WIDDOWSON et al Atty. Ref.: **36-1535**

Serial No. **Unknown** Group:

National Phase of: **PCT/GB00/02997**
International Filing Date: **3 August 2000**

Filed: **January 17, 2002** Examiner:

For: **SIGNAL GENERATOR AND DECODER**

* * * * * * * * * * *

January 17, 2002

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

PRELIMINARY AMENDMENT

Prior to calculation of the filing fee and in order to place the above identified application in better condition for examination, please amend as follows:

IN THE SPECIFICATION

Page 1, after the title insert the following:

-- This application is the US national phase of international application PCT/GB00/02997 filed August 3, 2000 which designated the U.S. --.

IN THE CLAIMS

Please substitute the following amended claims for corresponding claims previously presented. A copy of the amended claims showing current revisions is attached.

3. (Amended) A method according to claim 1, in which the complex spreading signal is derived from a sequence defined by the equation

where

$m = 0,1,2,\ldots, N-1$, q is any integer and the number of sequences of a given length is N.

4. (Amended) A method according to claim 1 in which the bandlimiting step is performed prior to the phase shifting step.

5. (Amended) A method according to claim 1 in which the bandlimiting step is performed after the upconversion step.

6. (Amended) A method according to claim 1 in which the modulation step is performed after the upconversion step.

10. (Amended) An apparatus according to claim 7, in which the data modulator is coupled to receive a second signal via the complex modulator.

REMARKS

Attached hereto is a marked-up version of the changes made to the claims by the current amendment. The attached page is captioned "**Version with markings to show changes made**."

The above amendments are made to place the claims in a more traditional format.

Respectfully submitted,

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

3. (Amended) A method according to claim 1 [or claim 2], in which the complex spreading signal is derived from a sequence defined by the equation

where

m = 0,1,2,..., N-1, q is any integer and the number of sequences of a given length is N.

4. (Amended) A method according to [any one of the preceding claims] <u>claim 1</u> in which the bandlimiting step is performed prior to the phase shifting step.

5. (Amended) A method according to [any one of claims 1 to 3] <u>claim 1</u> in which the bandlimiting step is performed after the upconversion step.

6. (Amended) A method according to [any one of the preceding claims] <u>claim 1</u> in which the modulation step is performed after the upconversion step.

10. (Amended) An apparatus according to [any one of claims 7 to 9] <u>claim 7</u>, in which the data modulator is coupled to receive a second signal via the complex modulator.

14/PRTS

10/031231

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Signal Generator and Decoder

This invention relates to a signal generator for providing a single sideband (SSB) spread spectrum signal.

Currently all cellular networks use double sideband modulation to upconvert a baseband signal to a radio frequency. Hence, the same information is conveyed in both sidebands, and the signal uses twice the bandwidth than is absolutely necessary. Single sideband modulation allows the same amount of information to be transmitted using half the bandwidth of double sideband modulation, or alternatively twice the amount of information in the same bandwidth.

The next generation of cellular networks is known as Universal Mobile Telecommunications Systems (UMTS). Wideband code division multiple access (W-CDMA) will be used for 60MHz of paired spectrum, i.e. two separate bands of 60MHz, the lower band being used for the uplink and the higher band being used for the downlink. The use of W-CDMA facilitates high bit rates for mobile users.

The capacity of a code division multiple access (CDMA) system is determined by the number of chips per symbol (known as the processing gain) divided by the energy per bit divided by noise power spectral density (Eb/No). If the number of chips per symbol can be increased then the capacity is increased. The maximum chipping rate is limited by the available bandwidth. Single sideband modulation reduces the bandwidth required by a modulated signal by a half. Therefore if a single sideband modulated signal can be produced then either the chipping rate can be increased, or two single sideband signals (upper and lower sideband) may be employed in order to increase the capacity of a CDMA system.

However, traditional techniques used to produce a single sideband signal, such as bandpass filtering or the well known phasing method cannot be used with data where the spectrum extends down to DC.

A known method of producing a single sideband signal is shown in Figure 1. However this complex modulator may not be used with traditional spreading codes such as PN code, Walsh codes, Gold code etc. to produce SSB because these codes are binary and do not provide a suitable complex spread spectrum signal. The autocorrelation and cross correlation properties of these signals are good. However, if the signal is transformed (eg. by the Hilbert transform) to produce a quadrature signal, then discontinuities and poor correlation properties result. Poor correlation properties result in an increase in the interference experienced by other users and thus decrease the capacity of the system. Hence, to use a modulator such as that shown in Figure 1 a spreading code is required which has good correlation properties in both the real and imaginary domains if a corresponding increase in capacity is to be achieved.

Complex spreading codes with the desired properties are known, for example Frank-Zadoff-Chu (FZC) codes as described in "Polyphase codes with good non-periodic correlation properties", R. L. Frank, IEEE Transactions of Information Theory, vol. IT-9, pp. 43-45, Jan. 1963. However, use of these codes produces a spread spectrum signal which is not bandlimited as will be shown later, so that whatever modulation is used the resulting signal would occupy limitless bandwidth. In "A class of bandlimited complex spreading sequences with analytic properties", M. P. Lotter and L. P. Linde, Proc of ISSSTA 95, 22-25 Sept. 1996, it was shown that by limiting the phase shift between successive samples of the sequence to be less than π radians, a bandlimited signal may be obtained and a set of codes called analytic bandlimited complex sequences derived. The penalty paid for this filtering process is that both the autocorrelation and crosscorrelation functions of the codes are no longer ideal so the number of users which may be supported is reduced. So, although the number of chips per symbol is increased in this known system, the resulting poor correlation properties do not result in a corresponding increase in capacity.

The present invention seeks to alleviate these problems by providing a single sideband spread spectrum signal generator in which single sideband modulation using a complex spreading code is achieved with improved correlation properties, so that the interference between users is reduced.

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According to the present invention there is provided a method of generating a single sideband spread spectrum signal comprising the steps of:

phase-shifting a complex spreading singal in accordance with a Hilbert transform to produce a phase-shifted complex spreading sigal;

upconverting the complex spreading signal and the phase-shifted complex spreading signal to a higher frequency to produce the single sideband spread spectrum signal,

bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

modulating one of the complex spreading signal or the single sideband spread spectrum signal with a received signal,

wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.

In a preferred embodiment of the invention the upconverting step comprises the substeps of modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part of the phase shifted complex signal.

Preferably the complex spreading signal is derived from a sequence defined by the equation
where

$m = 0,1,2,\ldots, N-1$, q is any integer and the number of sequences of a given length is N.

The bandlimiting step may be performed prior to the phase shifting step or the bandlimiting step may be performed after the upconversion step.

In some embodiments of the invention the modulation step is performed after the upconversion step.

According to a second aspect of the invention there is provided an apparatus for transmitting a single sideband spread spectrum signal, comprising: a complex spreading signal generator (1) for generating a complex spreading signal:

a phase shifter (3) coupled to receive the complex spreading signal via the complex spreading signal generator and for phase-shifting the complex spreading signal in accordance with a Hilbert Transform to provide a phase-shifted complex-spreading signal;

a complex modulator (6) coupled to receive the complex spreading signal and the phase-shifted complex spreading signal for upconversion thereof to produce the single sideband spread spectrum signal;

a bandlimiting filter (2; 2',2";8) for bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

a data modulator (4,5; 9) connected to receive an input signal for modulating one of the complex spreading signal or the single sideband spread spectrum with the input signal.

In some embodiments of the invention the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator. In other embodiments of the invention the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.

In some embodiments of the invention the data modulator is coupled to receive a second signal via the complex modulator.

According to another aspect of the invention there is provided a method of decoding a single sideband signal comprising the steps of phase shifting a complex spreading signal in accordance with a Hilbert Transform; upconverting the complex spreading signal to a higher frequency; and demodulating a received signal in accordance with the upconverted complex spreading signal.

Preferably the complex spreading signal is derived from a sequence defined by the equation
where

$m = 0,1,2,\ldots, N-1$, q is any integer and the number of sequences of a given length being N.

According to another aspect of the invention there is provided an apparatus for decoding a transmitted signal, comprising: a complex spreading signal generator; a phase shifter connected to receive the complex spreading signal from the complex spreading signal generator; a complex modulator connected to receive the complex spreading signal from the complex spreading signal generator, connected to receive the phase shifted complex spreading signal from the phase shifter and arranged in operation to upconvert the complex spreading signal; and a data modulator connected to receive the transmitted signal and the upconverted complex spreading signal and arranged in operation to demodulate the transmitted signal to provide a decoded transmitted signal.

Methods of and apparatus for generating and decoding signals according to the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a known modulator for producing a single sideband transmission signal from an arbitrary information source;

Figure 2 shows a known complex modulator for producing a single sideband transmission signal from complex input data.

Figures 3a to 3e show embodiments of a signal generator according to the invention;

Figure 4 shows ideal autocorrelation and cross correlation functions for a spreading signal of length 49 chips;

Figure 5 shows complex spreading signals for use in a signal generator according to the invention;

Figure 6 shows schematically how a signal generator according to the invention may be employed in different ways to increase capacity in a system;

Figure 7 is a graph showing bit error rate (BER) against the number of users for a system using a signal generator according to the invention, BER for a standard UMTS system using double sideband modulation and BER for a system employing a combination of the techniques which would represent the evolutionary route in the adoption of the invention where SSB and DSB systems co-exist in the same spectrum;

Figure 8 illustrates how a higher chipping rate can reduce fading (destructive interference) due to multipath propagation;

Figure 9 shows how BER varies with the time delay between a line of sight signal and an equal magnitude signal of random phase, representing the same signal received via a different path;

Figure 10 shows results taken from channel sounding measurements in a typical microcellular environment demonstrating the small inter-arrival delays between multipaths in a dense urban environment; and

Figure 11 shows a decoder for decoding a signal transmitted according to the invention.

Figure 1 shows a known modulator for producing a SSB. A data signal I and its corresponding quadrature signal Q are modulated at modulators 10 and 13 by a cosine wave of the modulation frequency. The data signals I and Q are also modulated at modulators 12 and 11 by a sine wave of the modulation frequency. The outputs of the modulators 10 and 11 are fed to an adder 14 providing an SSB signal 16 and the outputs of the modulators 12 and 13 are fed to an adder 15 to provide an SSB output signal 17. The output at 16 is 90 degrees out of phase with the output at 17. The modulator of Figure 1 provides an upper sideband signal, a lower sideband signal may be produced by changing the sign of one of the inputs to the adders 14 and 15. It will be appreciated that a modulator which simply produces one or the other of the output signals 16 or 17 could equally well be used.

Figure 2 shows a complex modulator for producing a SSB signal from a complex input signal. Complex signal B is the quadrature counterpart of complex signal A. The imaginary part of complex signal B is subtracted from the real part of complex signal A (via an inverter, not shown) at an adder 20, and the resultant summed signal is then modulated by a cosine wave of the modulation frequency at a modulator 23. Similarly, the imaginary part of complex signal A is added to the real part of complex signal B at an adder 21, and the summed signal is then modulated by a sine wave of the modulation frequency at modulator 22. The two modulated signals are summed at an adder 24 to produce an SSB signal. The complex modulator of Figure 2

produces an upper sideband signal, a lower sideband signal may be produced by changing the sign of one of the inputs to the adders 20 and 21.

Figure 3a shows a first embodiment of an SSB spread spectrum signal generator according to the invention comprising a complex spreading signal generator 1 which generates a complex spreading signal, denoted Re(ss) and Im(ss). The nature of the complex spreading signal will be described later with reference to Figure 5. The complex spreading signal is received by a low pass filter 2 which outputs a filtered complex spreading signal, the real part of which is denoted Re(F(ss)) and the imaginary part of which is denoted Im(F(ss)). The filter 2 is implemented as a root raised cosine filter, although any type of low pass filter could be used. A data signal modulates the real and imaginary complex spreading signals at modulators 4 and 5 to produce a modulated complex signal. The modulated complex signal is then phase shifted by 90 degrees using a Hilbert Transform filter 3 to produce the quadrature counterpart of the complex signal. These complex signals are then upconverted to the desired frequency by a complex modulator 6 to provide as an output an SSB spread signal. Cosine and sine waves of the desired frequency are provided by a signal generator 7.

Figure 3b shows an embodiment of the invention in which the complex signal is filtered after modulation by the input data. Equally filtering can be performed after the Hilbert transform, as shown in the embodiment of Figure 3c. This embodiment requires the use of two low pass filters 2′ and 2″. Figure 3d shows an embodiment of the invention in which the upconverted SSB signal is bandlimited by a band pass filter 8.

Figure 3e shows an embodiment of the invention in which the data modulates the upconverted SSB signal at a modulator 9. It will be appreciated that bandlimiting of the signal can be performed in several ways in a similar manner to the embodiments shown in Figures 3b, 3c and 3d.

For spread spectrum communications a set of spreading signals is required each of which has an autocorrelation function which is near zero everywhere except

at a single maximum per period, and which also has minimum cross correlation functions. It has been shown by D. V. Sarwate in "Bounds on crosscorrelation and autocorrelation of sequences", IEEE Transactions on Information Theory, vol IT-25, pp720-724, that the maximum magnitude of the periodic cross correlation function and the maximum magnitude of the periodic autocorrelation are related, and that if a set of signals has good autocorrelation properties then the cross correlation properties are not very good, and vice versa. Figures 4a and 4b show perfect autocorrelation and ideal cross correlation functions (for a spreading signal of length 49 chips)

The complex spreading signal generator 1 generates one of a family of complex spreading signals which have good correlation properties. The codes used in this embodiment of the invention are known as Frank-Zadoff-Chu (FZC) sequences or codes. They are based on the complex roots of unity:

$$W_N = e^{-i2\pi r/N}$$

Where $i=\sqrt{-1}$, N denotes the FZC sequence length and r is an integer relatively prime to N. The FZC sequences are then defined as:

$$\begin{aligned} a_m &= W_N^{m^2/2+qm} && N \text{ even} \\ &= W_N^{m(m+1)/2+qm} && N \text{ odd} \end{aligned}$$

where m = 0,1,2,..., N-1 and q is any integer and the number of sequences of a given length is N.

The maximum instantaneous frequency reached by the sequence $\{a_m\}$ is when m = N-1, and can be written as:

$$\omega_{a\max} = 2\pi r(1-\frac{1}{2N})$$

$$\omega_{a\max} \approx 2\pi\ r$$

for large N

Clearly the maximum instantaneous frequency is not bandlimited to the Nyquist value for the chipping rate and depends upon r. The real and imaginary parts of an FZC sequence are shown in Figure 5a. The sequence generated by the complex spreading sequence generator 1 is phase shifted by the Hilbert Transform filter 3 to produce a signal which has been phase shifted by 90 degrees. The phase shifted sequence corresponding to the complex sequence of Figure 5a is shown in Figure 5b. The complex spreading sequence and the transformed sequence each have good autocorrelation and good cross correlation properties.

The operations of bandlimiting, applying the Hilbert transform, and upconversion to a broadcast frequency using a complex modulator may be performed in any order, as long as the Hilbert Transform is applied before the upconversion step. Hence, in alternative embodiments of the invention the order in which the signals are filtered, spread and modulated is different. For example, referring again to Figure 3, the complex spreading signal from the spreading signal generator 1 may be phase shifted by the Hilbert transform filter 3 and then the complex spreading signal and the phase shifted spreading signal may each be filtered, although in this case two low pass filters would be required. Figure 3e shows another alternative embodiment of the invention in which the data is used to modulate the upconverted spread spectrum signal.

The capacity of the system is potentially increased because either two SSB signals may be used in a single existing UMTS channel or one SSB channel of twice the chipping rate may be employed, as shown schematically in Figure 6. For a practical system which allows a smooth transition from a standard using double sideband modulation to a standard using SSB modulation, it is desirable that a signal employing SSB modulation and a signal employing double sideband modulation should cause minimal interference to each other. Figure 7 shows the results of an experiment to measure the BER against the number of users for a system using SSB modulation according to the preferred embodiment of the invention, the BER for a standard

UMTS system using double sideband modulation and the BER for a system employing a combination of the techniques, referred to as an 'overlay' in Figure 7.

An advantage of using an SSB channel of twice the chipping rate is that multipath resolution is improved. Multipath resolution is required when a signal may take a plurality of paths between a transmitter and a receiver. If the multipath resolution is improved, the potential increase in capacity is more than 100%, due to reduced fading and hence decreased interference. Figure 8 illustrates how a higher chipping rate can reduce interference, if it is possible to resolve signals received via different paths. It is also possible to constructively combine signals received via different paths so that the performance of a line with multipaths may actually be improved over that of a perfect channel.

Figure 9 shows how BER varies with the time delay between a line of sight signal and an equal magnitude signal of random phase, representing the same signal received via a different path. In this example the chipping rate is 4 Mchip/s with a period of 0.25 s and the Eb/No is 6.8dB resulting in a BER of 1×10^{-3} when no multipath interference occurs. In this example the sampling point is midway through the chip resulting in the start of the next chip occurring after a delay 0.125 s. It can be seen that the low BER is maintained until the two signals are spaced by less than the chipping period then significant fading (destructive interference) results and the BER increases significantly.

Figure 10 shows results taken from channel sounding measurements in a typical microcellular environment. A significant multipath is defined as paths which have a signal strength within 10 dB of the strongest signal. In the graph of Figure 10 the profile width is plotted against the number of significant multipaths. It can be seen that, in many cases, all of the energy is distributed within a 0.5 s window, even when many paths are contributing. If the chipping period is 0.25 s many separate multipaths will arrive within each chip interval resulting in fading and thus degradation of system performance. Therefore, for much of the time the system is only able to resolve 2 multipaths. Increasing the chip rate not only reduces fading

but also yields more resolvable multipaths which could beneficially be combined at the receiver.

Figure 11 shows a decoder for decoding the transmitted signal of this invention. A despreading signal is generated using a spreading signal generator 1′, a Hilbert transform filter 3′, a quadrature signal generator 7′ and a complex modulator 6′ in a similar manner to the generation of the spreading signal shown in Figure 3e. The transmitted data is demodulated, and despread by a modulator 9, and then low pass filtered by a low pass filter 10 to achieve the decoded signal.

CLAIMS

1. A method of generating a single sideband spread spectrum signal comprising the steps of:

phase-shifting a complex spreading singal in accordance with a Hilbert transform to produce a phase-shifted complex spreading sigal;

upconverting the complex spreading signal and the phase-shifted complex spreading signal to a higher frequency to produce the single sideband spread spectrum signal,

bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

modulating one of the complex spreading signal or the single sideband spread spectrum signal with a received signal,

wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.

2. A method according to claim 1, in which the upconverting step comprises the substeps of

modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and

modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part of the phase shifted complex signal.

3. A method according to claim 1 or claim 2, in which the complex spreading signal is derived from a sequence defined by the equation

where

m = 0,1,2,..., N-1, q is any integer and the number of sequences of a given length is N.

4. A method according to any one of the preceding claims in which the bandlimiting step is performed prior to the phase shifting step.

5. A method according to any one of claims 1 to 3 in which the bandlimiting step is performed after the upconversion step.

6. A method according to any one of the preceding claims in which the modulation step is performed after the upconversion step.

7. An apparatus for transmitting a single sideband spread spectrum signal, comprising: a complex spreading signal generator (1) for generating a complex spreading signal:

a phase shifter (3) coupled to receive the complex spreading signal via the complex spreading signal generator and for phase-shifting the complex spreading signal in accordance with a Hilbert Transform to provide a phase-shifted complex-spreading signal;

a complex modulator (6) coupled to receive the complex spreading signal and the phase-shifted complex spreading signal for upconversion thereof to produce the single sideband spread spectrum signal;

a bandlimiting filter (2; 2',2";8) for bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

a data modulator (4,5; 9) connected to receive an input signal for modulating one of the complex spreading signal or the single sideband spread spectrum with the input signal.

8. An apparatus according to claim 7, in which the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator.

9. An apparatus according to claim 7, in which the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.

10. An apparatus according to any one of claims 7 to 9, in which the data modulator is coupled to receive a second signal via the complex modulator.

11. A method of decoding a single sideband signal comprising the steps of

upconverting the complex spreading signal to a higher frequency; and

demodulating a received signal in accordance with the upconverted complex spreading signal.

12. A method according to claim 11, in which the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2+qm} && N \text{ even} \\ &= W_N^{m(m+1)/2+qm} && N \text{ odd} \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

m = 0,1,2,..., N-1, q is any integer and the number of sequences of a given length being N.

13. An apparatus for decoding a transmitted signal, comprising:

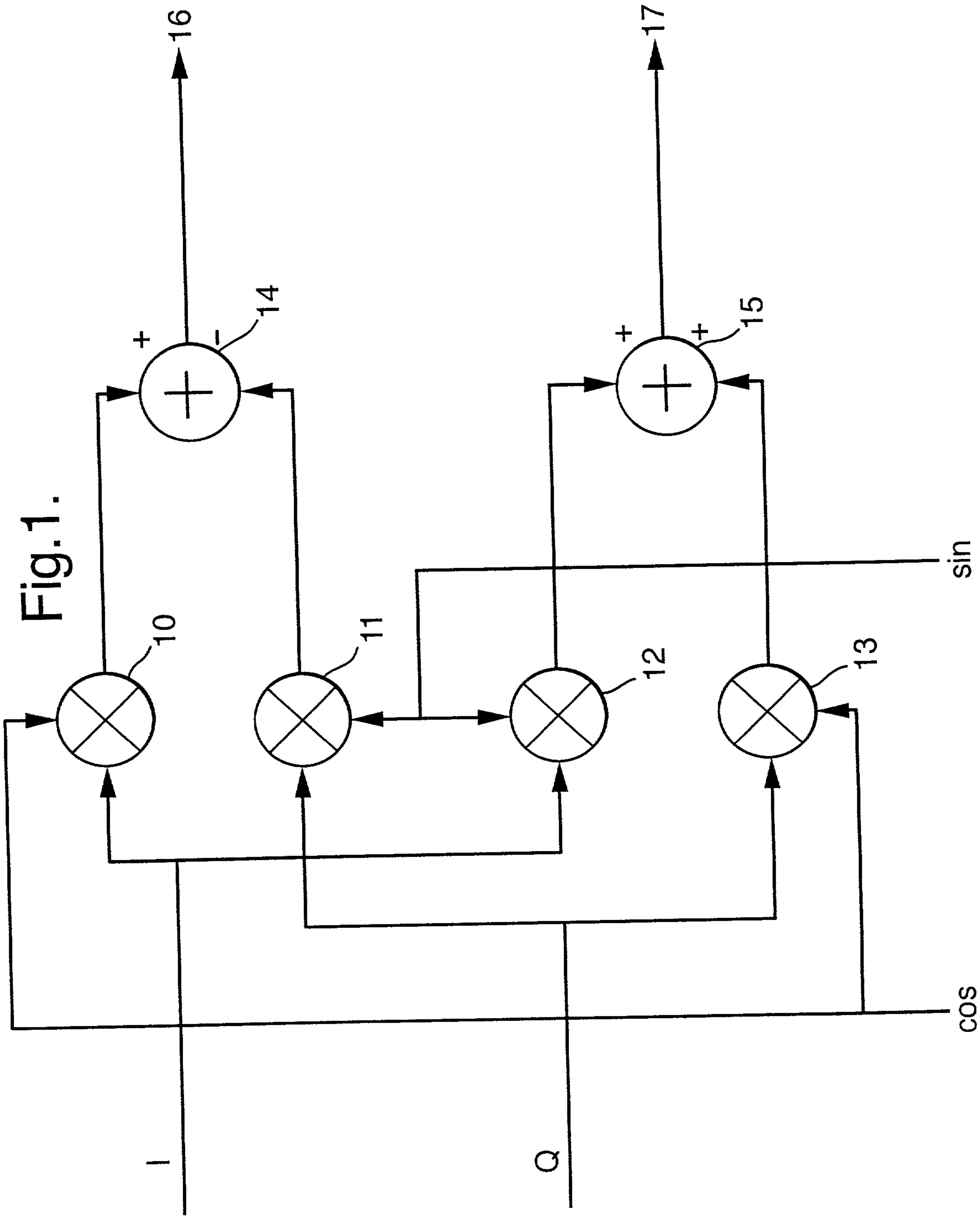
a complex spreading signal generator;

a phase shifter connected to receive the complex spreading signal from the complex spreading signal generator;

a complex modulator connected to receive the complex spreading signal from the complex spreading signal generator, connected to receive the phase shifted complex spreading signal from the phase shifter and arranged in operation to upconvert the complex spreading signal; and

a data modulator connected to receive the transmitted signal and the upconverted complex spreading signal and arranged in operation to demodulate the transmitted signal to provide a decoded transmitted signal.

Fig.1.



10/031231

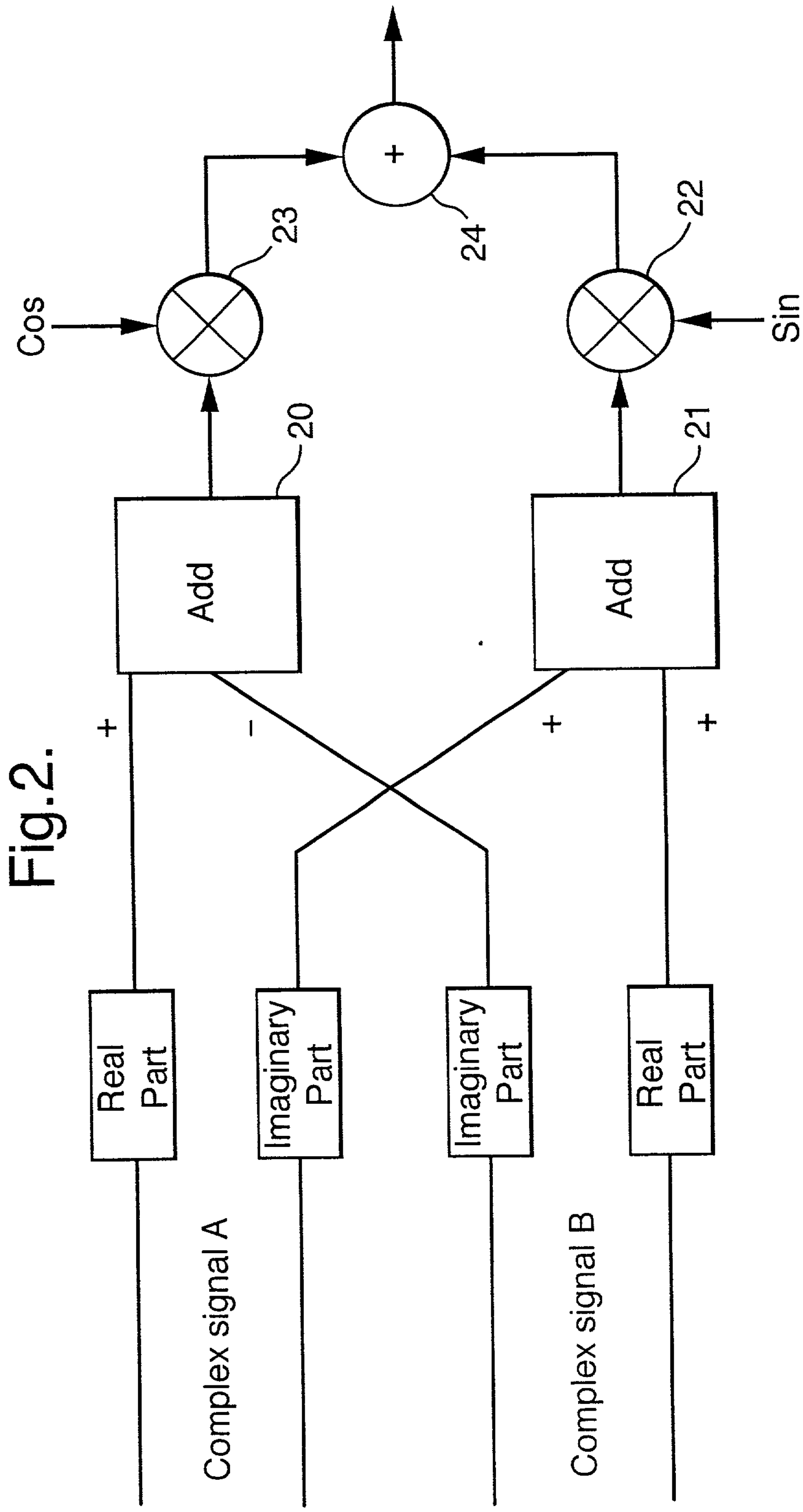
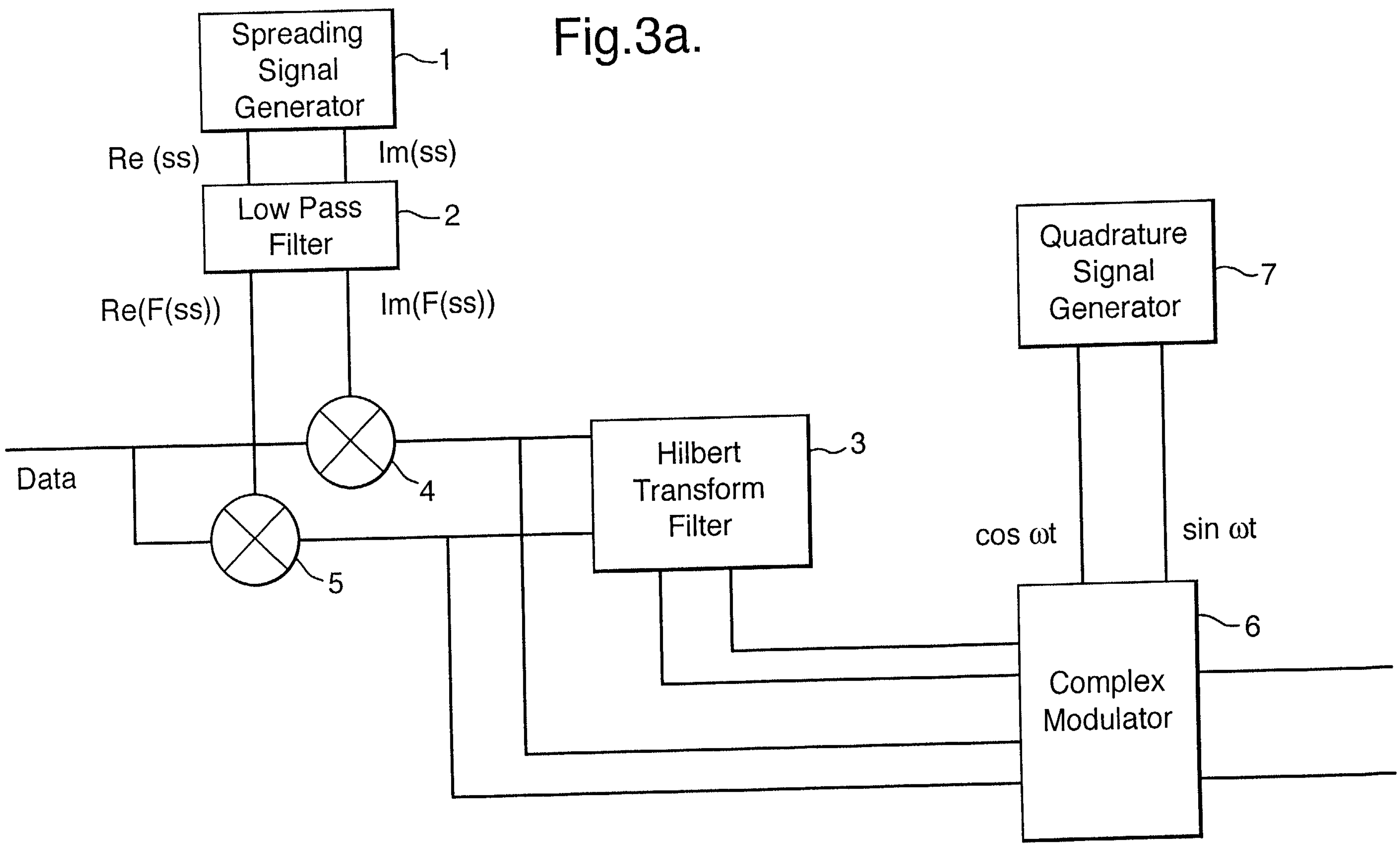


Fig.2.

Fig.3a.


Spreading Signal Generator
1
Re (ss)
Im(ss)
Low Pass Filter
2
Re(F(ss))
Im(F(ss))
Data
4
5
Hilbert Transform Filter
3
Quadrature Signal Generator
7
cos ωt
sin ωt
Complex Modulator
6

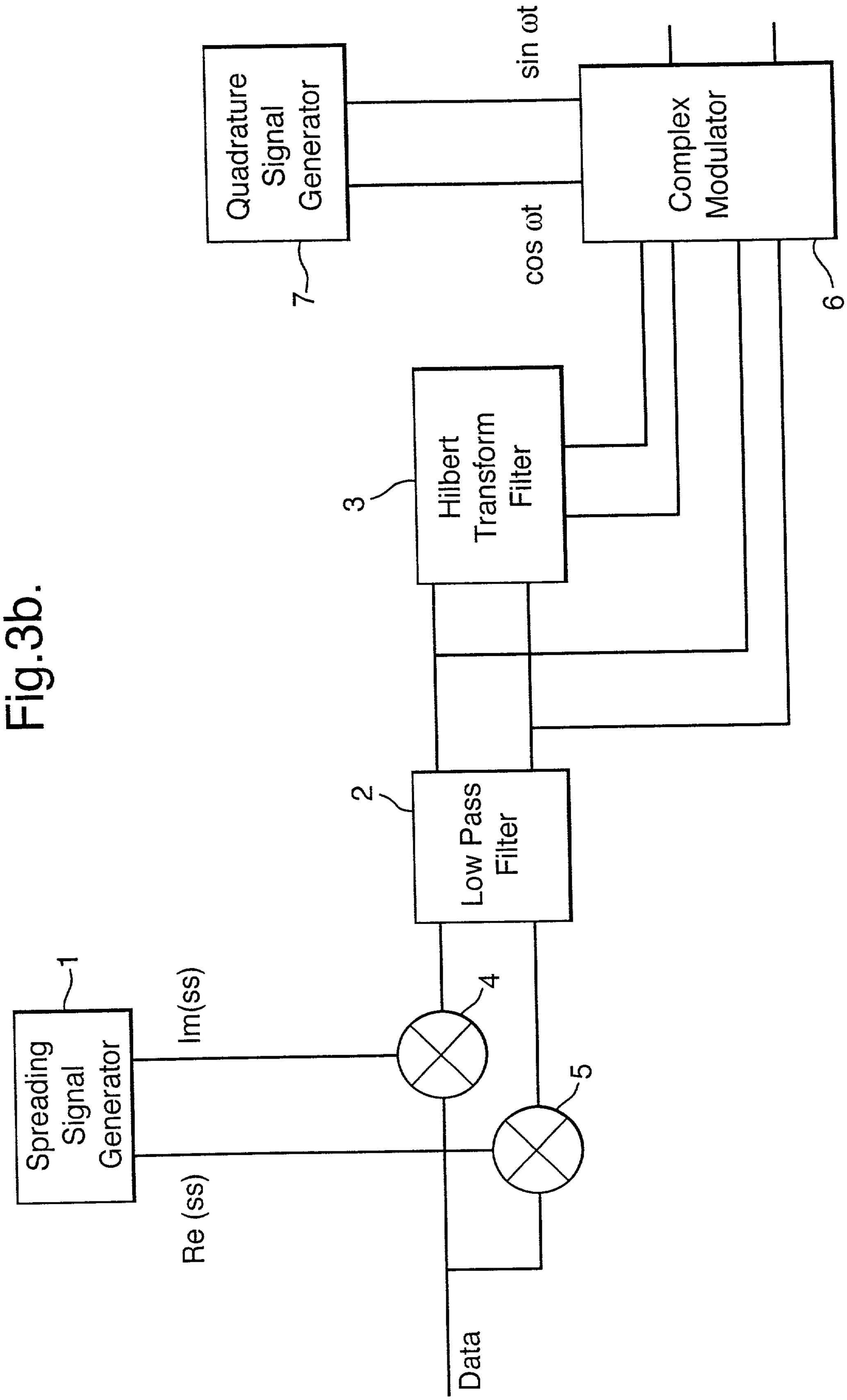
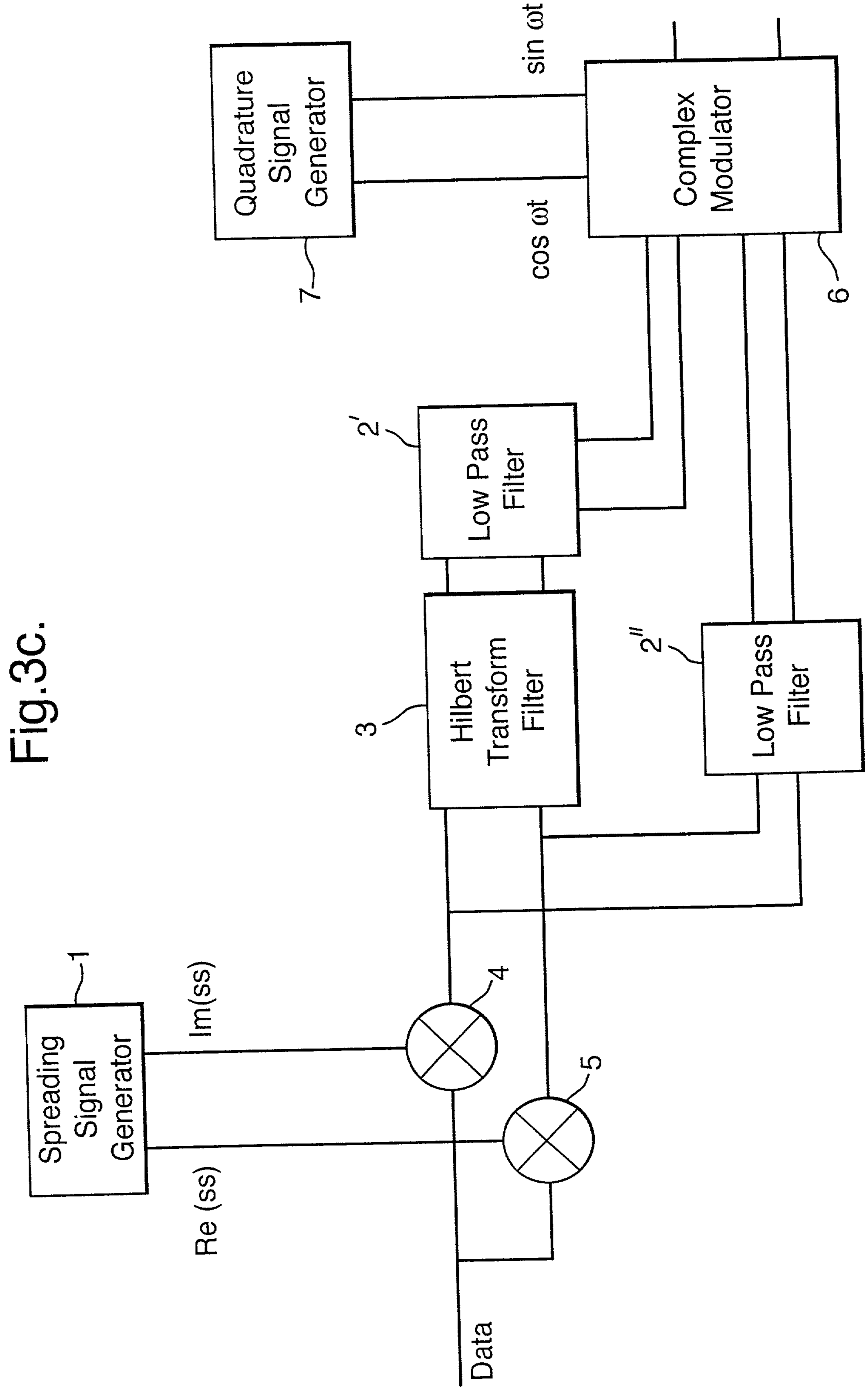

Quadrature Signal Generator
7
sin ωt
cos ωt
Complex Modulator
6
Hilbert Transform Filter
3
Low Pass Filter
2
Spreading Signal Generator
1
Im(ss)
Re (ss)
4
5
Data

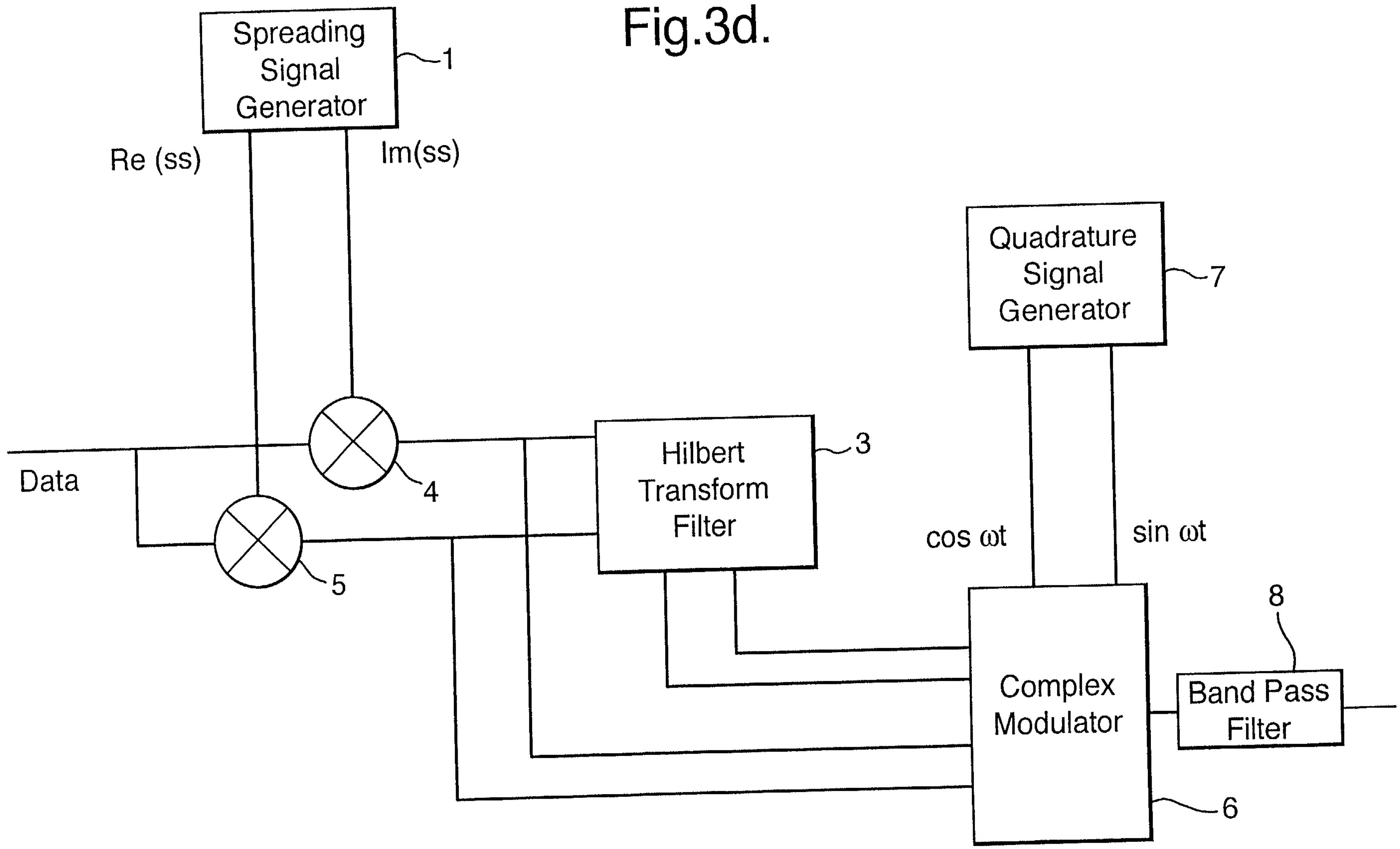
Fig.3b.



Quadrature Signal Generator
7
sin ωt
cos ωt
Complex Modulator
6
Low Pass Filter
2'
Hilbert Transform Filter
3
Low Pass Filter
2''
Spreading Signal Generator
1
Im(ss)
Re (ss)
4
5
Data

Fig.3c.

Fig.3d.


Spreading Signal Generator
1
Re (ss)
Im(ss)
Data
4
5
Hilbert Transform Filter
3
Quadrature Signal Generator
7
cos ωt
sin ωt
Complex Modulator
6
Band Pass Filter
8

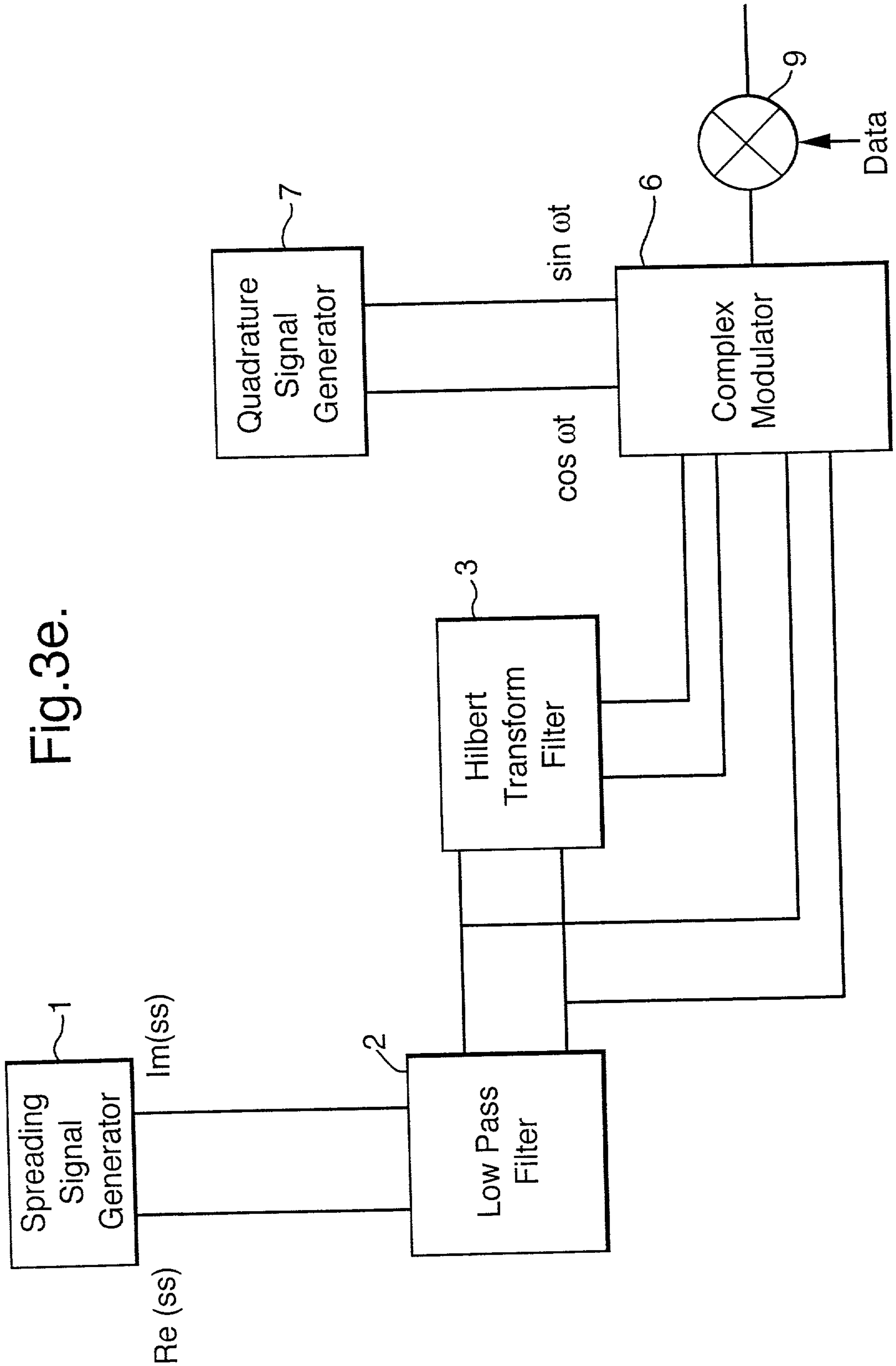

Quadrature
Signal
Generator
7
sin ωt
cos ωt
6
Complex
Modulator
9
Data
3
Hilbert
Transform
Filter
1
Spreading
Signal
Generator
Im(ss)
Re (ss)
2
Low Pass
Filter

Fig.3e.

Fig.4a.

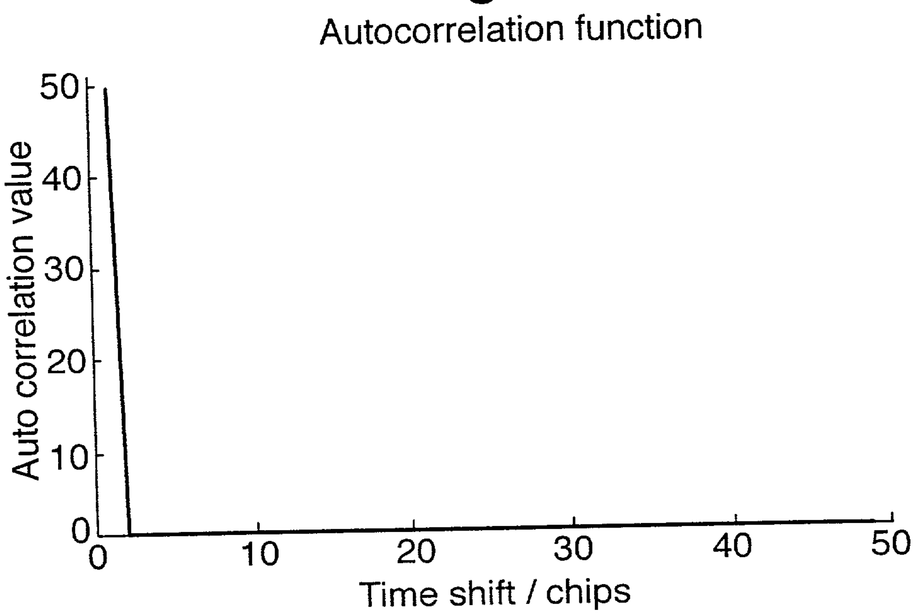

Autocorrelation function
Auto correlation value
50
40
30
20
10
0
0
10
20
30
40
50
Time shift / chips

Fig.4b.

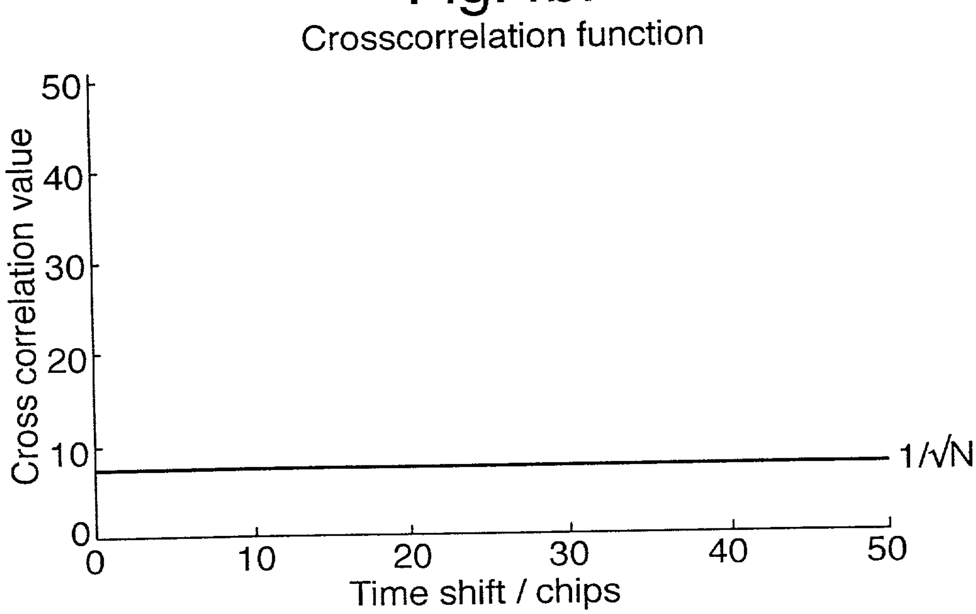
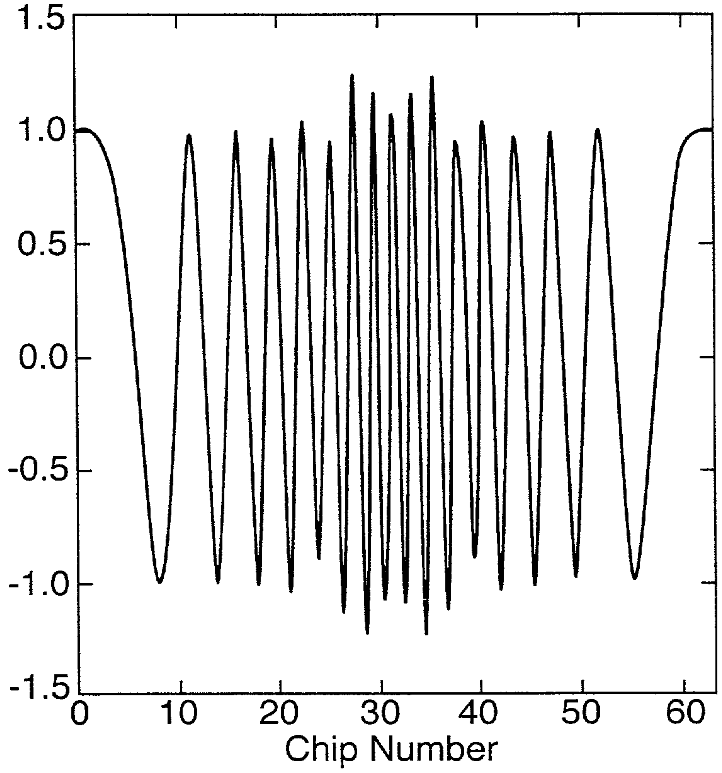

Crosscorrelation function
Cross correlation value
50
40
30
20
10
0
0
10
20
30
40
50
1/√N
Time shift / chips

Fig.5a.

Filtered FZC Sequence (Seq 1 of length 63) - REAL



Filtered FZC Sequence (Seq 1 of length 63) - IMAGINARY

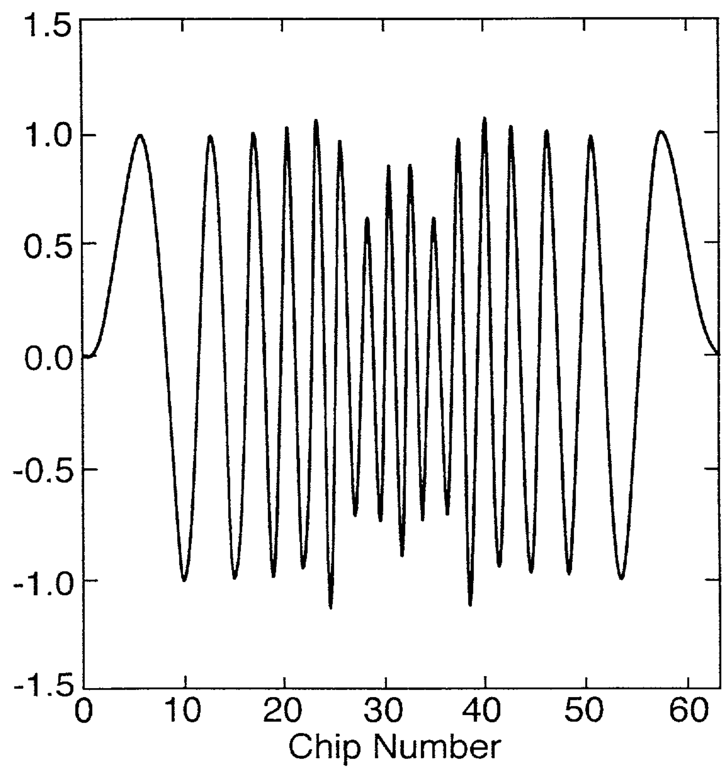
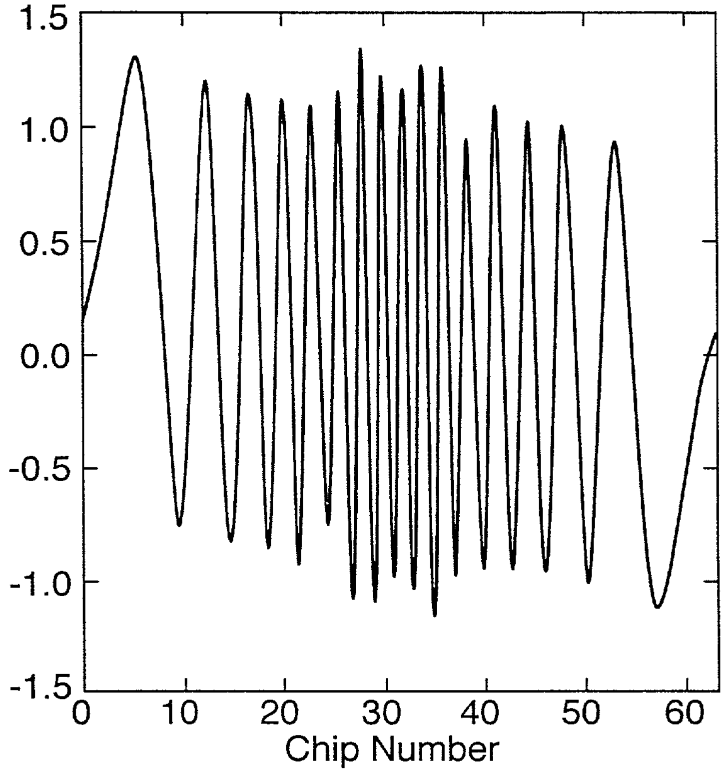


Fig.5b.

Hilbert T-form of Filtered FZC Sequence
(Seq 1 of length 63) - REAL



Hilbert T-form of Filtered FZC Sequence
(Seq 1 of length 63) - IMAGINARY

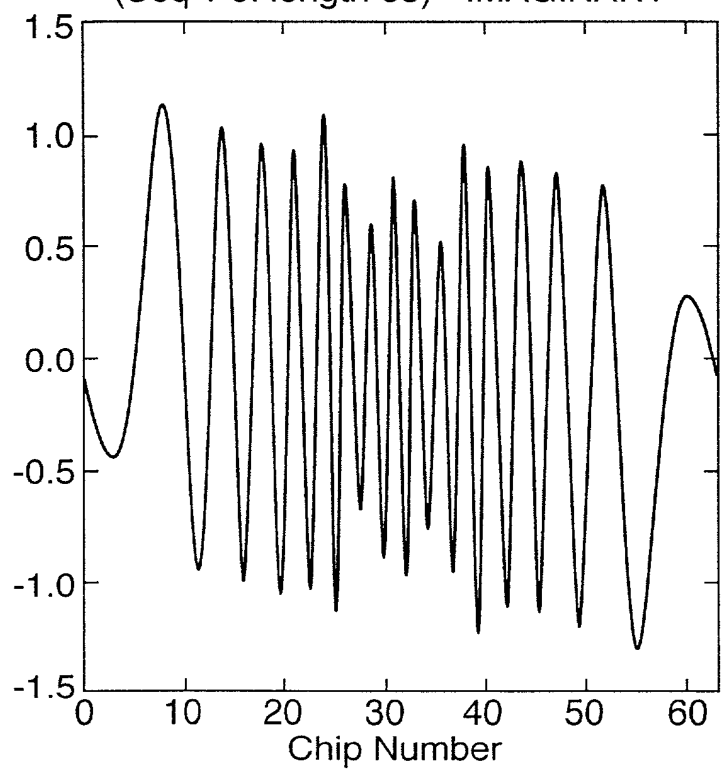


Fig.6.

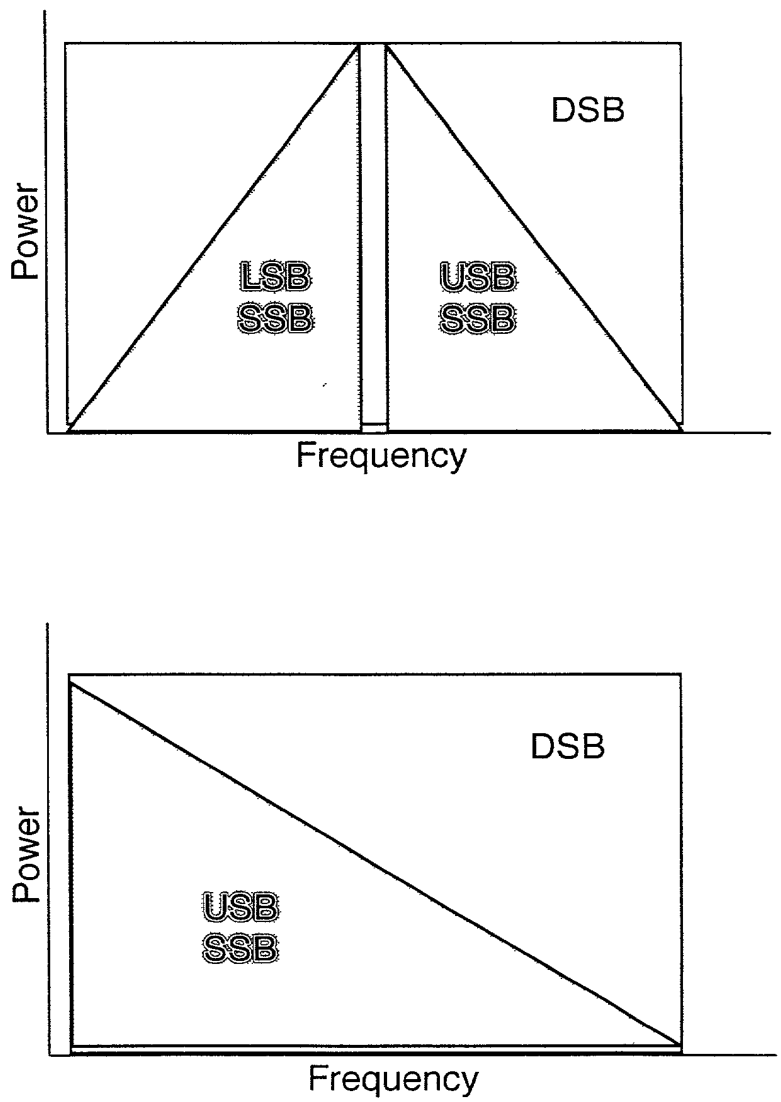

DSB
Power
LSB
SSB
USB
SSB
Frequency
DSB
Power
USB
SSB
Frequency

Fig.7.

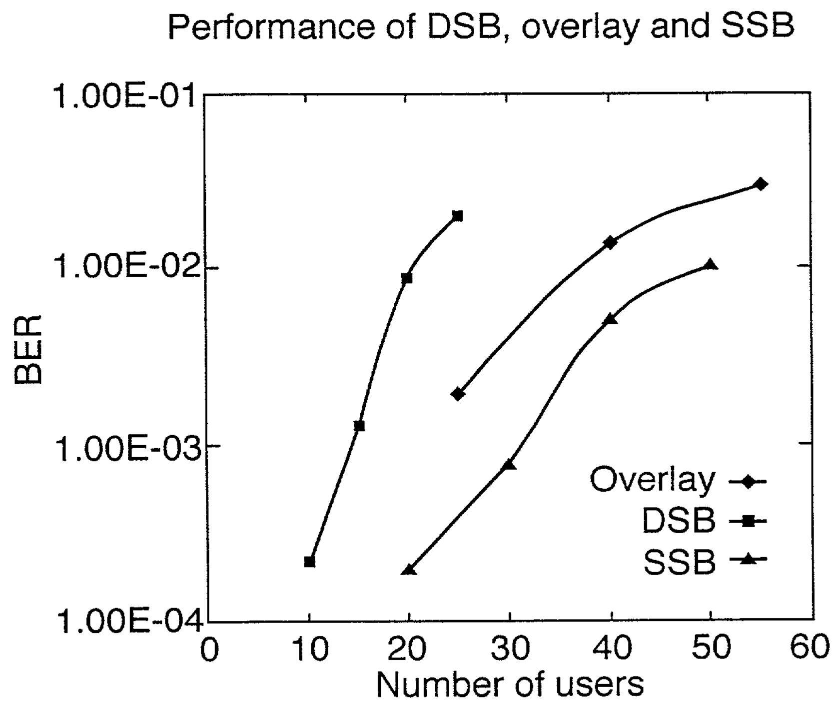

Performance of DSB, overlay and SSB
1.00E-01
1.00E-02
1.00E-03
1.00E-04
BER
0
10
20
30
40
50
60
Number of users
Overlay
DSB
SSB

Fig.8.

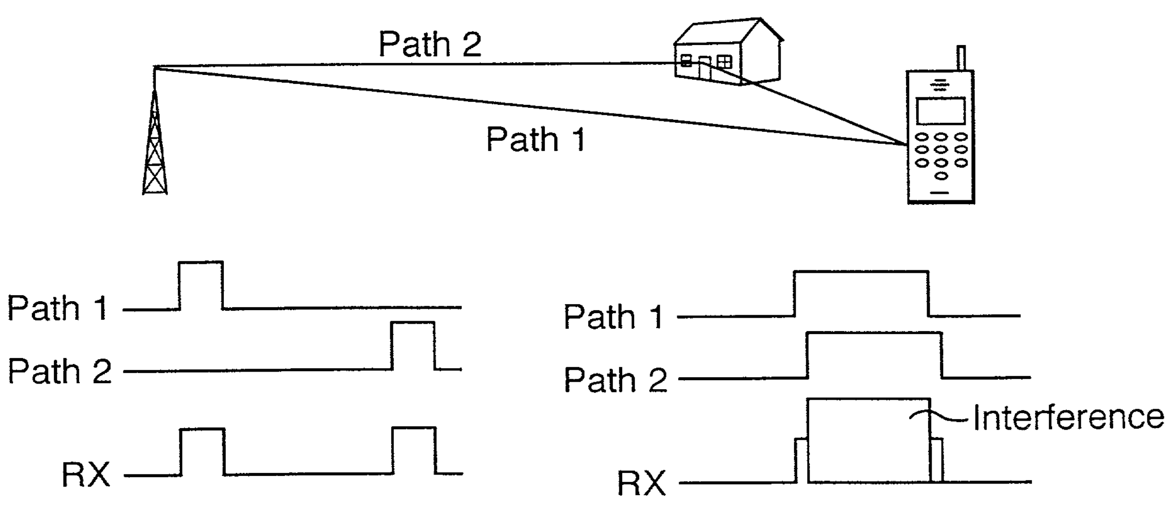

Path 2
Path 1
Path 1
Path 2
RX
Path 1
Path 2
Interference
RX

Fig.9.

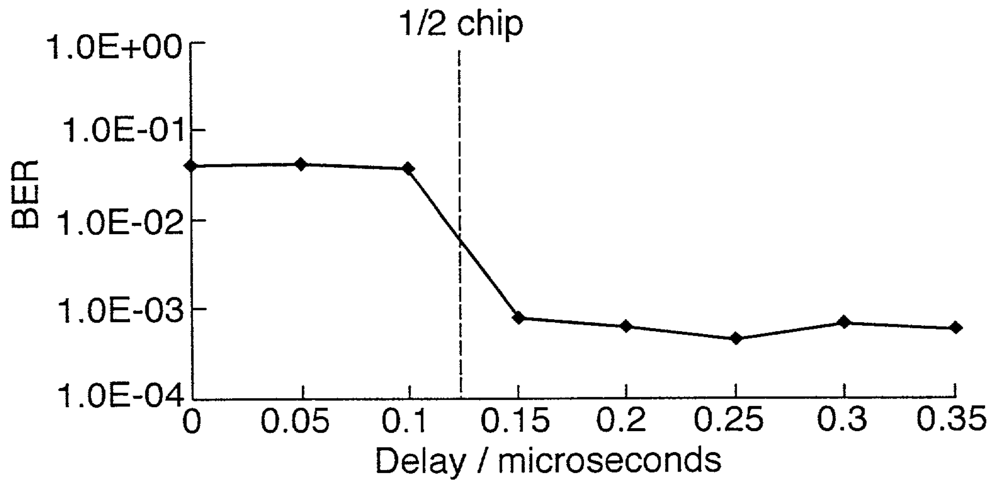

1/2 chip
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
BER
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Delay / microseconds

Fig.10.

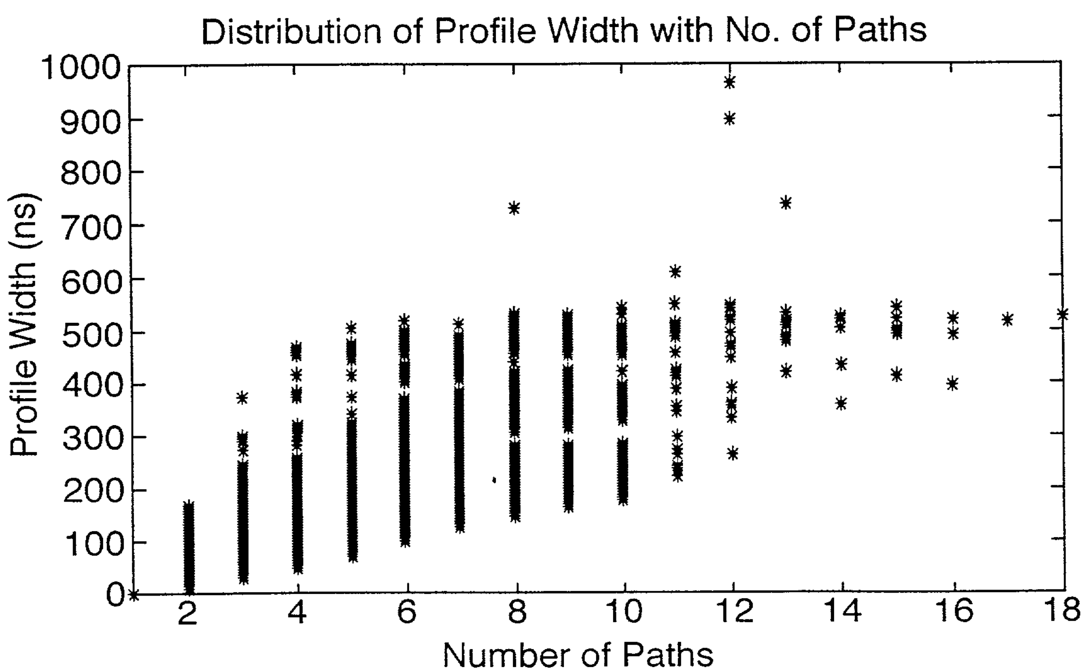
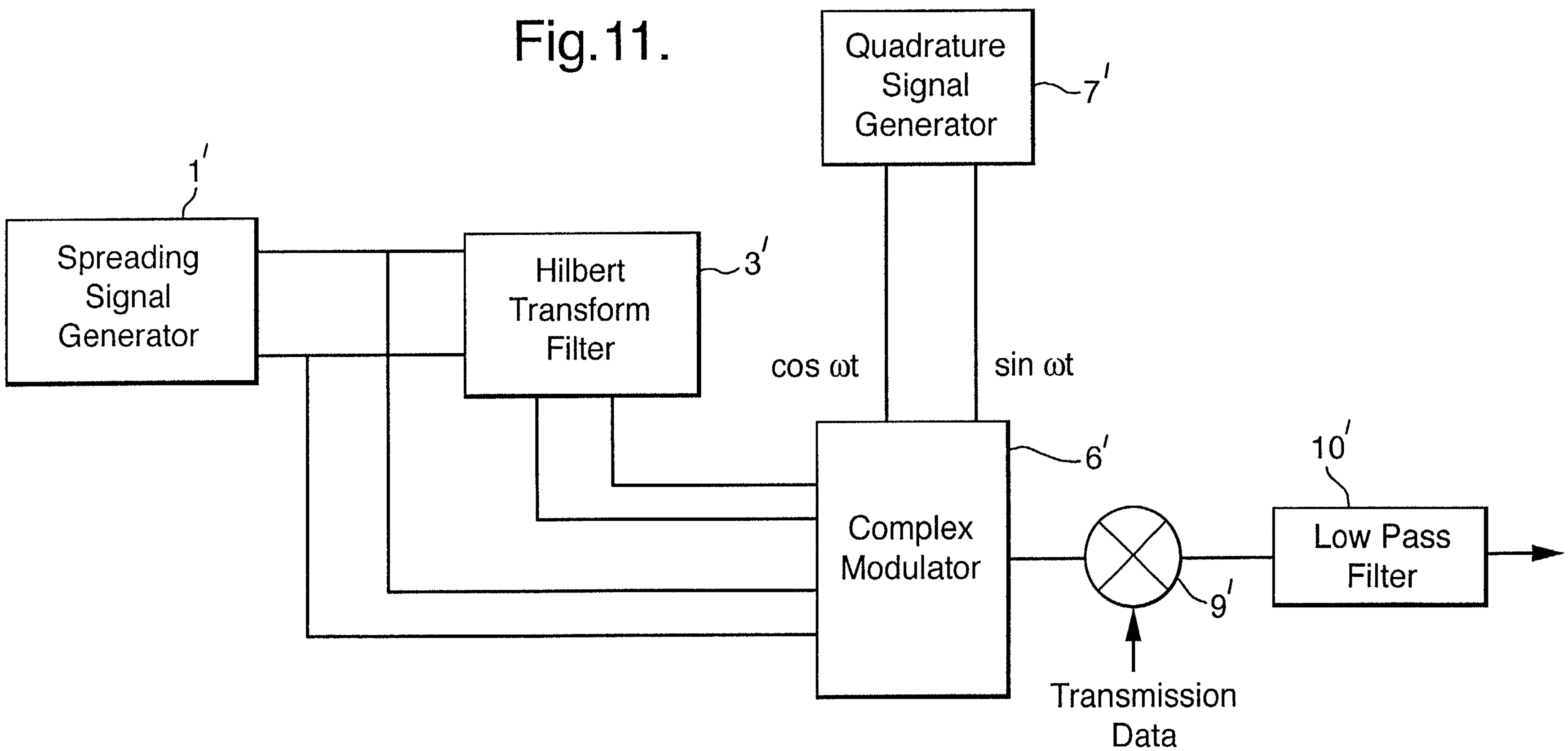

Distribution of Profile Width with No. of Paths
1000
900
800
700
600
500
400
300
200
100
0
Profile Width (ns)
2
4
6
8
10
12
14
16
18
Number of Paths

Fig.11.


Spreading
Signal
Generator
1'
Hilbert
Transform
Filter
3'
Quadrature
Signal
Generator
7'
cos ωt
sin ωt
Complex
Modulator
6'
9'
Transmission
Data
Low Pass
Filter
10'

Nixon & Vanderhye P.C. (10/99)
(Domestic Non-Assigned/Foreign)

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SIGNAL GENERATOR AND DECODER

the specification of which (**check** applicable **box(s)**):

☐ is attached hereto

☐ was filed on ____________ as U.S. Application Serial No. ____________ (Atty Dkt. No. -)

☒ was filed as PCT International application No. **PCT/GB00/02997** on **3 AUGUST 2000**

and (if applicable to U.S. or PCT application) was amended on ____________

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed or, if no priority is claimed, before the filing date of this application:

Priority Foreign Application(s):

Application Number	Country	Day/Month/Year Filed
99306490.6	EUROPE	17 AUGUST 1999

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

Application Number	Date/Month/Year Filed

I hereby claim the benefit under 35 U.S.C. 120/365 of all prior United States and PCT international applications listed above or below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior applications in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose material information as defined in 37 C.F.R. 1.56 which occurred between the filing date of the prior applications and the national or PCT international filing date of this application:

Prior U.S./PCT Application(s): Application Serial No.	Day/Month/Year Filed	Status: patented pending, abandoned
PCT/GB00/02997	3 AUGUST 2000	PENDING

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon. And on behalf of the owner(s) hereof, I hereby appoint **NIXON & VANDERHYE P.C., 1100 North Glebe Rd., 8th ~~Floor, Arlington, VA~~ 22201-4714, telephone number (703) 816-4000 (to whom all communications are to be directed)**, and the following attorneys thereof (of the same address) individually and collectively owner's/owners' attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent: Arthur R. Crawford, 25327; Larry S. Nixon, 25640; Robert A. Vanderhye, 27076; James T. Hosmer, 30184; Robert W. Faris, 31352; Richard G. Besha, 22770; Mark E. Nusbaum, 32348; Michael J. Keenan, 32106; Bryan H. Davidson, 30251; Stanley C. Spooner, 27393; Leonard C. Mitchard, 29009; Duane M. Byers, 33363; Jeffry H. Nelson, 30481; John R. Lastova, 33149; H. Warren Burnam, Jr. 29366; Thomas E. Byrne, 32205; Mary J. Wilson, 32955; J. Scott Davidson, 33489; Alan M. Kagen, 36178; Robert A. Molan, 29834; B. J. Sadoff, 36663; James D. Berquist, 34776; Updeep S. Gill, 37334; Michael J. Shea, 34725; Donald L. Jackson, 41090; Michelle N. Lester, 32331; Frank P. Presta, 19828; Joseph S. Presta, 35329 I also authorize Nixon & Vanderhye to delete any attorney names/numbers no longer with the firm and to act and rely solely on instructions directly communicated from the person, assignee, attorney, firm, or other organization sending instructions to Nixon & Vanderhye on behalf of the owner(s). JY

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